Case Study of Structural Modifications To Existing Explosives Manufacturing Facility For Enhanced Capabilities and Increased Personnel Safety

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ABSTRACT

The AMC-R 385-100 Safety Manual requires that facility modernization efforts involving an increase in explosive limits include provisions to upgrade existing facilities to meet explosion resistant construction criteria set forth in TM 5-1300, "Structures To Resist The Effects of Accidental Explosions." Through a Safety Enhancement Modernization project for a Lead Styphnate and Tetracene manufacturing facility, analysis was conducted to determine the structural sufficiency of the kettle room reinforced concrete walls (RCW) to withstand the gas and shock pressures generated by increased explosive quantities while providing Protection Category I per TM 5-1300 for facility operating personnel. The RCW were analyzed at 2° deflection as allowed for Protection Category I and were found to be insufficient to provide personnel protection during an incident of proposed increased explosive limits. The RCW were then analyzed to determine their explosive resistance in accordance with current TM construction criteria. The walls were found to have structural sufficiency adequate for an explosive limit significantly below the proposed modernization quantities and at no better than Protection Category IV. Different methods were considered which would strengthen the walls to current TM standards for increased explosive limits and provide increased personnel protection. The considered solution is a partial rebuild of the facility that will be designed in accordance with the 1990 edition of TM 5-1300.

BACKGROUND: The drawings for the Lead Styphnate building known as Building 85 are dated 1942 for construction of the original building which had only five (5) kettle rooms. In 1956 two kettle rooms were added at each end of the mix area corridor, making a total of nine (9) kettle rooms. New kettle room walls were constructed in the same manner as the original walls. The elevation difference between the resident personnel portion of the building and the mix corridor is 14'6" and drops another 9'6" from the mix corridor to the waste treatment tanks.
Each kettle room is essentially the same in dimension and equipment layout. The kettle room interior dimensions are 15' wide between substantial dividing wall (SDW), 13' tall from floor to ceiling and extending another 2'6" to top of parapet. The SDW for the kettle rooms are 14'6" long between corridor wall and frangible wall and then extend another 18 inches to the outside.

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The roof and the frangible walls are wood construction. The roof is 2" x 10" beams with 2" x 3" bridging. The wood framing is covered with 1 1/2" insulation and built-up ply roofing. The frangible walls are constructed of 2" x 6" studs, 16" on-center, covered with transite siding exterior and 1/4" masonite sheeting interior and insulated with 2" insulation batting. The frangible walls sit on a six inch tall and wide curb. The weight of the frangible wall is approximately 10 psf. There are two (2) doorways to the kettle rooms, the corridor door which is located 8 inches away from the corner of the room and constructed of 1" thick steel plate and a double doorway located off-center in the frangible wall with wood frame metal clad doors.

The SDW between kettle rooms and the corridor wall between the kettle room and the personnel corridor are constructed of reinforced concrete, 24" thick with #4 rebar on 16" centers vertically, 24" centers horizontally, each face. No shear reinforcement or lacing is shown in the building drawings. Drawings show the concrete is 2500 psi, however, the design assumption was that the concrete had increased in design strength by 20% to 3000 psi due to its age of 50 years. No information was available about the reinforcing steel so it was assumed to be 40,000 psi as was common in the 1940's.

The explosive mix kettles are currently located in the rooms approximately 5' from the closest SDW, 5' from the corridor wall and 3' above the floor to base of kettle. The proposed location for the modernization project with remote control kettles is centered in the room and 6' above the floor to the base of the kettle. Also considered for this structural analysis was a kettle location centered between the SDW and 4'10" from the frangible wall which is 1/3 the distance between the frangible wall and the corridor wall. Situating the kettle closer to the frangible wall would result in faster venting of an explosion and therefore lower gas pressures.

ANALYSIS: The 1942 walls of Building 85 were analyzed for structural response to explosions from varying amounts of Lead Styphnate and Tetracene in an effort to establish the actual explosive resistant strength of the walls in accordance with 1990 TM standards. Analysis began with the current production batch sizes for Lead Styphnate and Tetracene, 19# and 16# respectively.

SHOCK, FRANG and CBARCS software programs were used exclusively for the analysis. In brief, SHOCK calculates the average shock pressure and impulse generated by a specified quantity of explosive material and dependent upon the geometry of the room. Shock pressures are high intensity, short duration in nature. FRANG calculates gas pressures and impulses, again dependent upon room geometry and the amount of venting. Gas pressures are typically lower pressure and longer duration than shock pressures.

The CBARCS program applies the shock and gas pressure against a concrete slab or wall of given thickness, reinforcement and dimensions and determines the dynamic response of the wall. Specifically two (2) deflections are computed and compared to determine if a wall fails or withstands the explosion: allowable maximum deflection (AMD) for a wall to develop without failing; and actual maximum deflection (MD) developed by a wall experiencing

pressures from a given quantity of explosive.

Other considerations included the two (2) TNT equivalencies required for shock pressure calculations and gas pressure calculations, as well as determining what extent of personnel protection is required. The TNT equivalencies for the explosive materials were calculated in accordance with Chapter 2 of TM 5-1300. The Heat of Explosion and Heat of Combustion for the specific explosive material is divided by the same coefficients for TNT. The TNT equivalent weight is then increased by a 20% safety factor again in accordance with TM 5-1300. The TNT equivalency is calculated the same way whether the explosive is wet or dry. The values for the Heat of Explosion and the Heat of Combustion for Lead Styphnate, Tetracene and TNT were taken from AMCP 706-177. For 16# Tetracene the shock pressure TNT equivalent is 11.7# TNT and the gas pressure TNT equivalent is 3.5# TNT (both including the 20% safety factor increase). For 19# Lead Styphnate the shock pressure TNT equivalent is 9.6# TNT and the gas pressure TNT equivalent is 7.9# TNT (both including the 20% safety factor increase).

For the Lead Styphnate and Tetracene manufacturing process which involves production personnel working in adjacent bays to the mixing operation, it is necessary to provide Personnel Protection Category I per Chapter 1 of the TM. Personnel Protection Category I is partially defined as "...provides attenuation of blast pressures and structural motion to a level consistent with personnel tolerances..."

Based upon Figure 3-2 in TM 5-1300 which illustrates potential yield lines for two-way elements, the corridor wall and SDW were analyzed separately as the length/height ratio and the rigid support or fixity of each differs. The SDW between kettle rooms are fixed on 2 sides, at the corridor wall intersection and at the floor. The corridor wall was analyzed in two ways due to the closeness of the door to the SDW intersection. The doorway in essence creates a yield line. First it was analyzed as if there were no door, rigidly supported on three sides, at each SDW intersection and at the floor. Secondly it was analyzed as fixed on two sides, at the SDW farthest from the door and at the floor, and with the length of the corridor wall shortened, extending from the far SDW to the nearest jamb of the door.

Figure 4-17 in TM 5-1300 correlates the maximum degree of deflection allowed for walls stressed to their ultimate resistance while providing a given category of personnel protection. For Protection Category I, walls without shear reinforcement (stirrups) or tension membrane action are limited to 1°. Tension membrane action is developed when there is wall fixity on at least three sides. If either criteria is met then the maximum allowable deflection increases to 2°. For close-in incident protection, deflections above 2° are permitted only when shear reinforcement and tension membrane action are present, regardless of Protection Category classification. This is because the concrete fails in compression at 2° deflection and the steel must be present to transfer loads once the concrete has failed.

Even without stirrups and tension membrane action, the analysis of the Building 85 walls was begun with the 2° deflection limitation in order to establish an approximate quantity of explosives the walls could withstand. If the walls could withstand a quantity of explosive

close to current production requirements, it was considered likely that the walls could be clad with steel plate to contain fragments and thereby provide appropriate levels of personnel protection.

RESULTS: Starting with Lead Styphnate at the existing kettle location and testing the SDW, the wall was structurally sufficient for up to 5# of Lead Styphnate at the 2° deflection limitation. The allowable maximum deflection (AMD) was 5.147" and the maximum deflection (MD) of the wall at 5# was 4.0486". For explosive weights greater than 5#, the MD exceeded the AMD. For example, at 6# the MD is 5.503" and at 9# the MD is 9.962". The AMD is constant and based upon the particular geometry of the wall and the degree deflection permitted by the wall construction.

Tetracene was analyzed at its proposed kettle location through the modernization project, which is 1' higher than the existing kettle location and centered in the room. At that location 7# Tetracene was the maximum for the 2° deflection limitation. Again the AMD is 5.147" and the MD achieved by 7# Tetracene is 3.478". At 8# the MD is 5.176".

The remainder of the analyses dealt with the corridor wall and Lead Styphnate. In an effort to optimize the explosive quantity, the mix kettle was located in two different locations, first centered within the room and second, centered in the width of the room and 4'10" from the frangible wall, one-third the distance between the frangible wall and the corridor wall.

The results for the corridor wall fell into a range due to the 2 analysis methods for 2 sides fixed and for 3 sides fixed. For the kettle at its centered position, the explosive weight limits were between 6# which passes for both fixities and 9#, with both fixities failing at 10#. The AMD for 2 sides fixed is 4.572" and for 3 sides fixed is 3.1481". At 7, 8 and 9# it is the 2 sides fixed analysis where failure occurs. MD for 2 sides fixed is 5.290", 6.670" and 7.987" for 7, 8 and 9# respectively. At 9# the 3 sides fixed MD is 3.048" which passes.

For the kettle location at the one-third distance from the frangible wall, the explosive weight range was between 7# and 10#. The AMD is independent of kettle location and therefore remains the same as before, 4.572" for 2 sides fixed and 3.1481" for 3 sides fixed. At 11# when both fixities fail, the MD is 9.009" for 2 sides fixed and 3.671 for 3 sides fixed.

Theoretically reducing the weight of the frangible wall from 10 psf to 2 psf and analyzing with the kettle in the centered position raised the explosive weight range to between 12# and 15#. The AMD does not change, 4.572" for 2 sides fixed and 3.1481" for 3 sides fixed. At 15# the MD for 2 sides fixed is 6.017" which fails and the MD for 3 sides fixed is 2.982" which passes.

One overpressure calculation was developed for Lead Styphnate at 19# to determine the impinging gas pressure upon the exterior face of the frangible wall for the immediately adjacent bay. The overpressure pressure is approximately 6 psi. The frangible wall was not analyzed to determine its response to the overpressure.

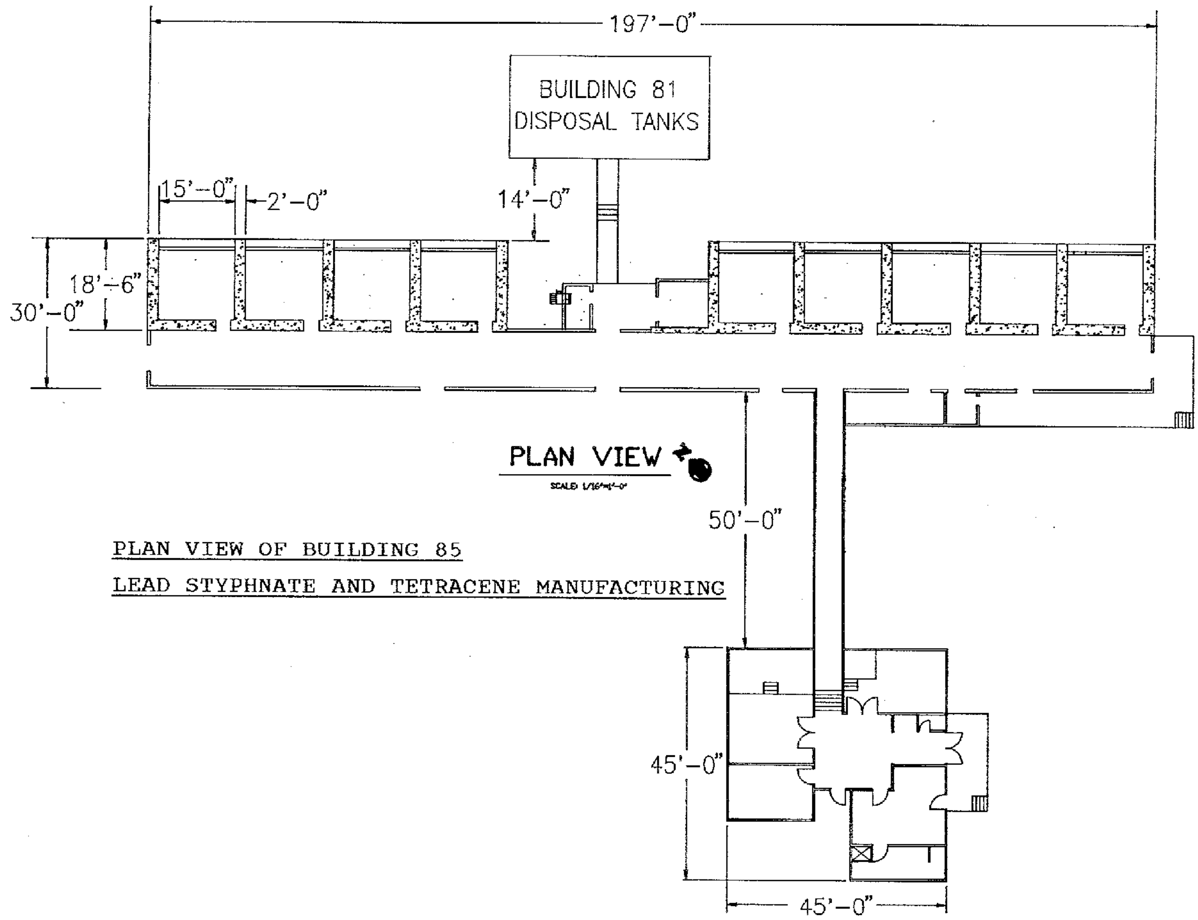
ANALYSIS SUMMARY: The results of the software analysis show that the amount of reinforcement steel in the 1942 walls of Building 85 is insufficient to meet the 1990 TM 5-1300 explosion resistant construction standards for Personnel Protection Category I. The structural sufficiency of the walls is adequate for quantities of explosive materials much less than current production requirements, therefore, the modernization project could not include increasing the production batch sizes in an effort to decrease personnel exposure. The analysis did show some gains in acceptable explosive quantities by assuming various modifications such as locating the kettle closer to the frangible wall for faster venting and decreasing the weight per square foot of the frangible wall. These gains however, were insufficient to meet minimum production requirements.

ALTERNATIVES: Consideration was now given to other kettle room modifications so that the goals of modernization and safety enhancement of the production process could be achieved. A preliminary design of a three-wall steel plate cubicle surrounding the remote control kettles, to be installed inside the existing mix rooms, was developed and cost estimated. The steel plate cubicle would be reinforced and rigidly supported with W8 x 31 mill steel all around, thereby taking all the shock loading from a blast and shielding the walls of the room. Shock pressures developed due to the close proximity of the steel plate barrier to the kettle were several thousand psi. The cost of the 1-inch steel plate and the mill steel plus new lightweight frangible walls and roof was excessive, especially relative to the anticipated production difficulties created by the crowded conditions of many runs of remote control electrical conduit and process piping, the substantial size of the three-wall steel plate cubicle and the large capacity kettle.

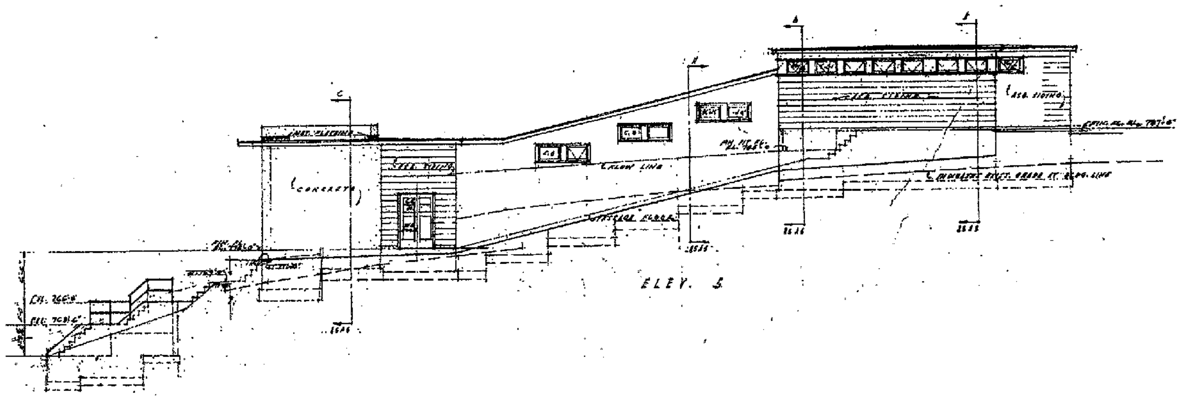
Given new large capacity kettles, production would require only four mix rooms for daily operations. Demolition of the four northern kettle rooms and reconstruction to meet 1990 TM standards was cost estimated and accepted as the necessary solution for the modernization project. Improved production capabilities are achieved through the installation of the remote control kettles and enhanced safety will be provided by the construction of reinforced concrete walls in accordance with 1990 TM standards.

The reconstruction with new TM walls is currently at 95% design level. SHOCK, FRANG and CBARCS software programs have been the primary design tools. The TM walls are the same thickness as the 1942 walls, 24 inches. The gain in structural strength is achieved by the inclusion of shear reinforcement as required to provide Personnel Protection Category I and the closer on-center spacing and larger size of rebar which enables the walls to withstand shock and gas pressures from the specified quantities of explosive materials. The diagonal reinforcement into the matt foundation and concrete roof develop the moment capacity of the walls. The concrete roof and walls for the ancillary equipment rooms provide blast overpressure protection for the production personnel in those areas.

PLAN VIEW OF BUILDING 85
LEAD STYPHNATE AND TETRACENE MANUFACTURING

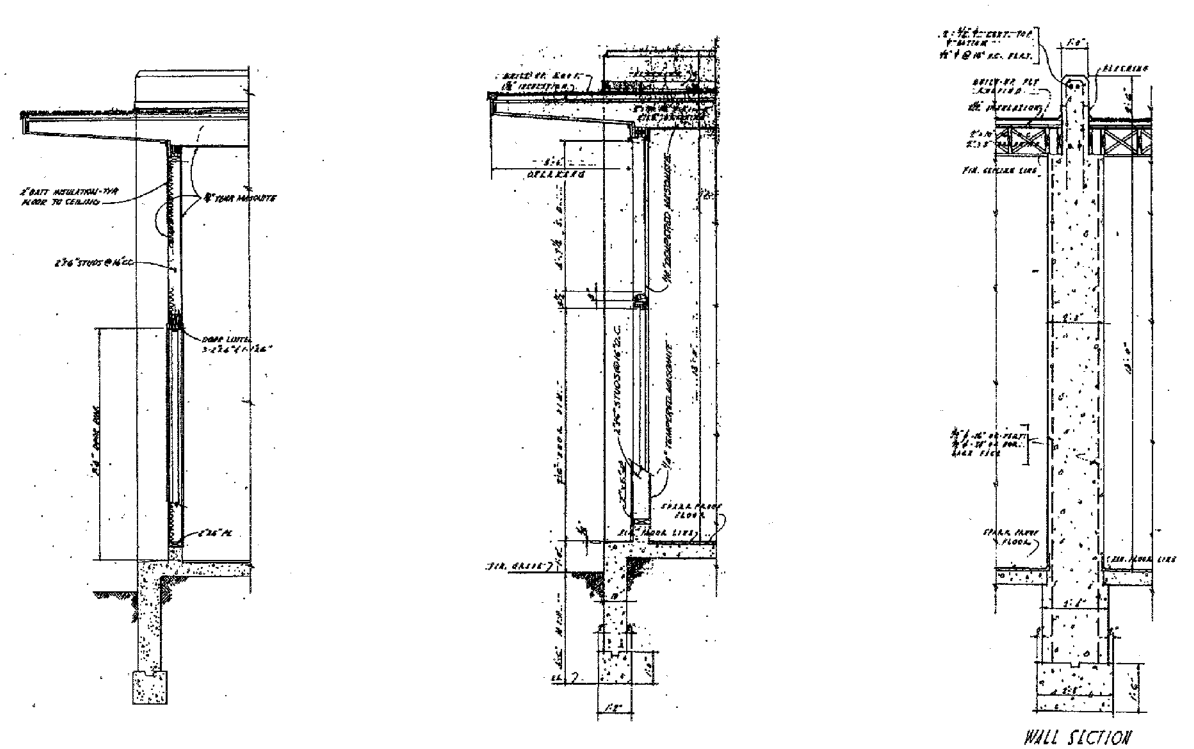


NORTH EXTERIOR ELEVATION OF BUILDING 85



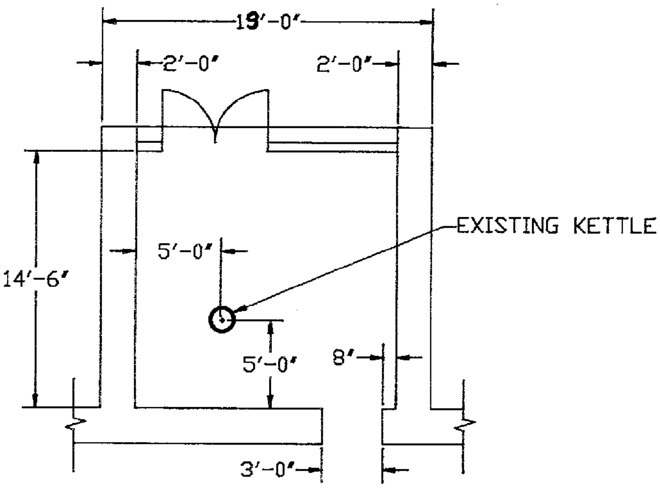
NORTH EXTERIOR ELEVATION OF BUILDING 85

CROSS SECTION OF FRANGIBLE WALL AND BLAST WALL

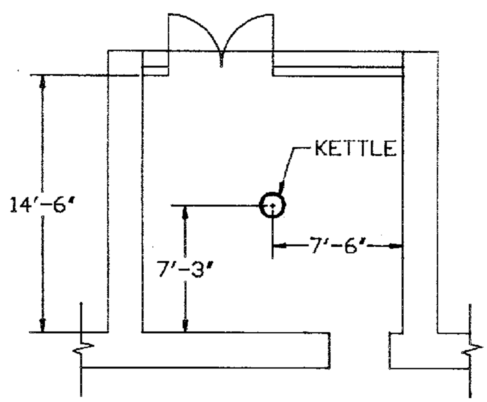


CROSS SECTION OF FRANGIBLE WALL AND BLAST WALL

PLAN VIEW OF EXISTING KETTLE ROOM



EXISTING KETTLE LOCATION
SCALE: 1/4"=1'-0"



KETTLE LOCATION
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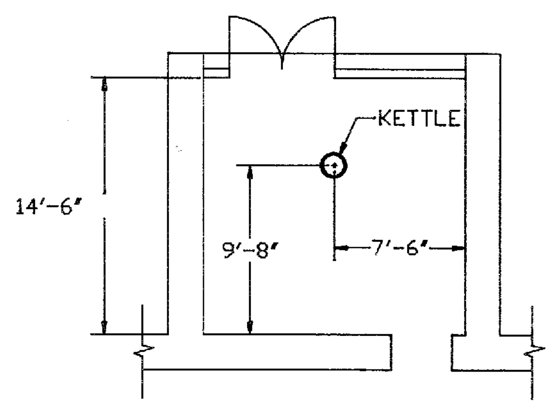
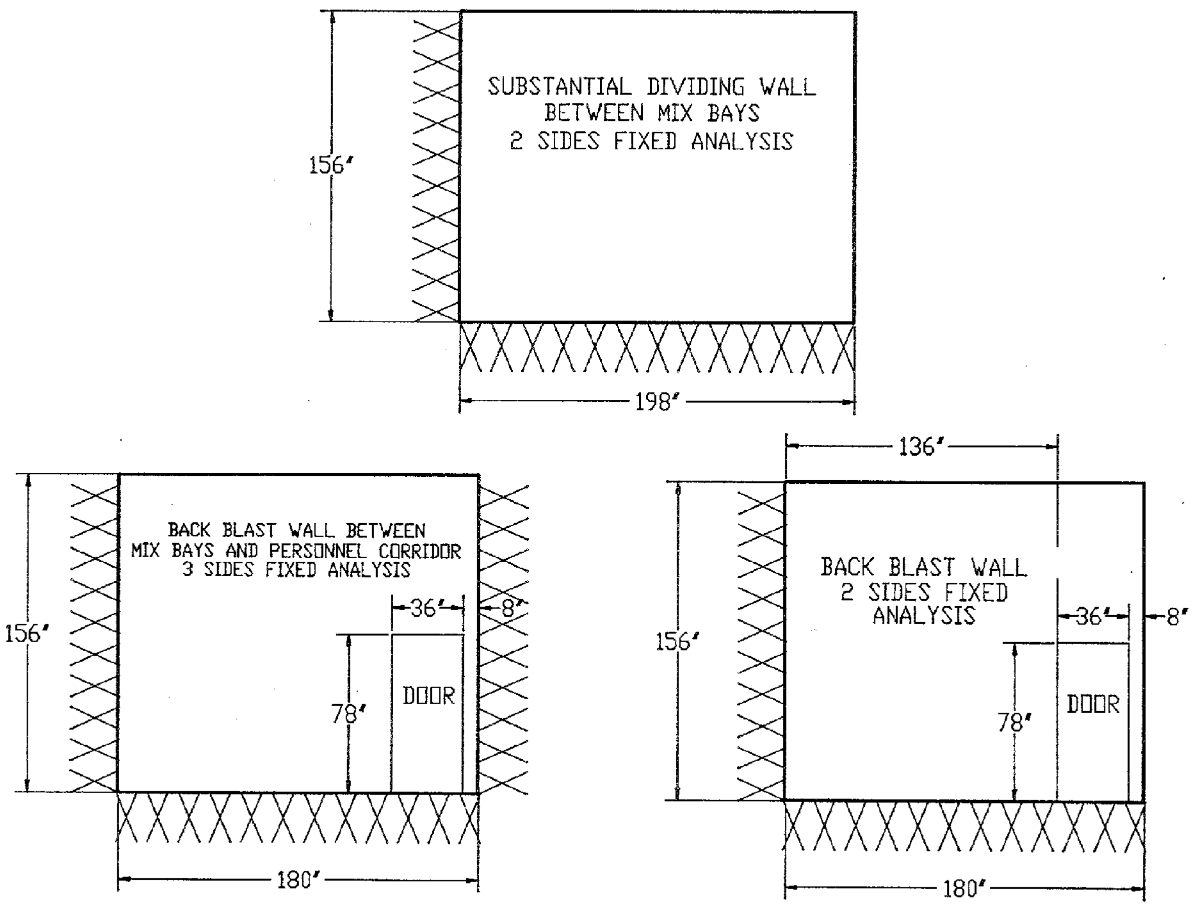


KETTLE LOCATION
SCALE: 1/4"=1'-0"

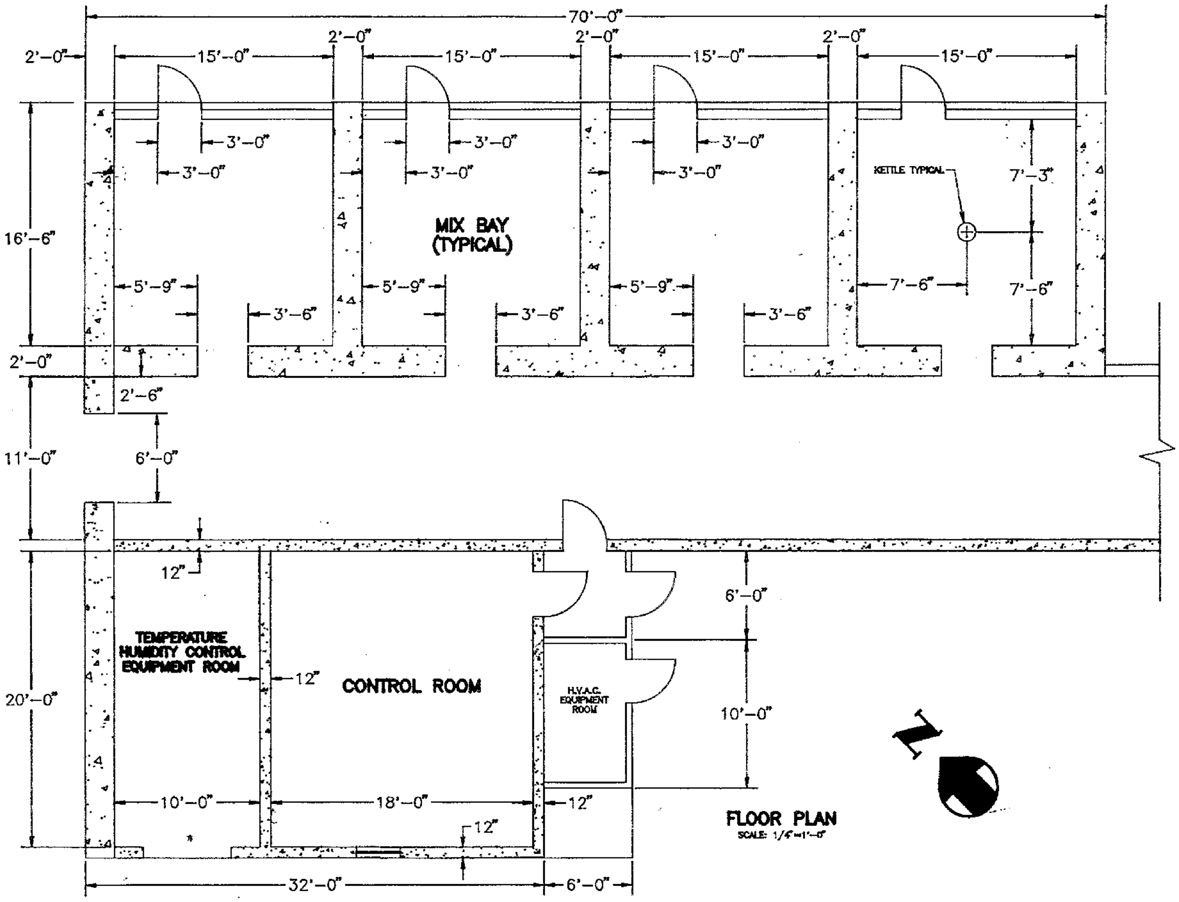
PLAN VIEW OF EXISTING KETTLE ROOM

WALL ELEVATIONS SHOWING RIGID SUPPORT (FIXITY) LOCATIONS



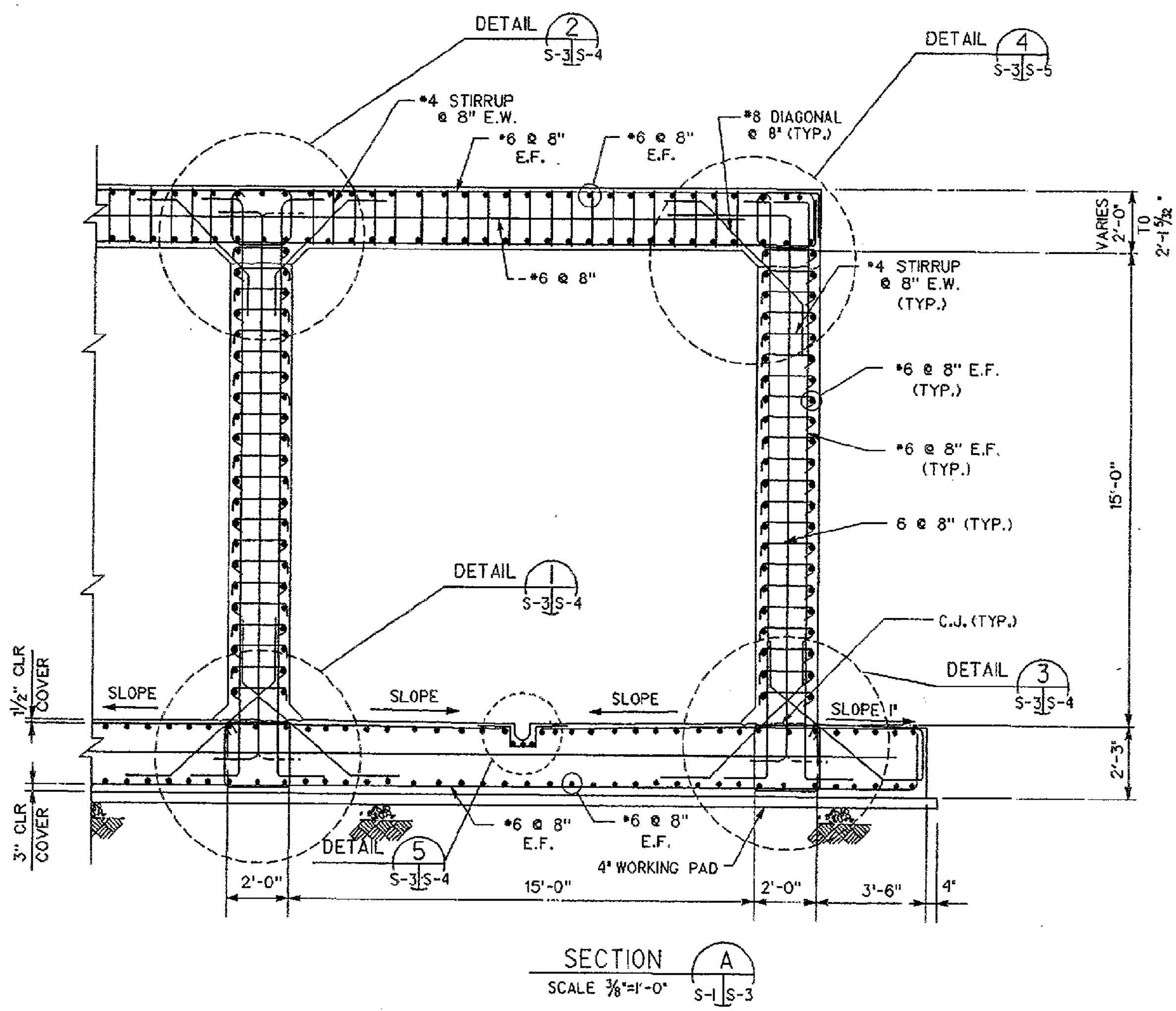
WALL ELEVATIONS SHOWING RIGID SUPPORT (FIXITY) LOCATIONS

PLAN VIEW OF BUILDING 85 MODERNIZATION CONSTRUCTION



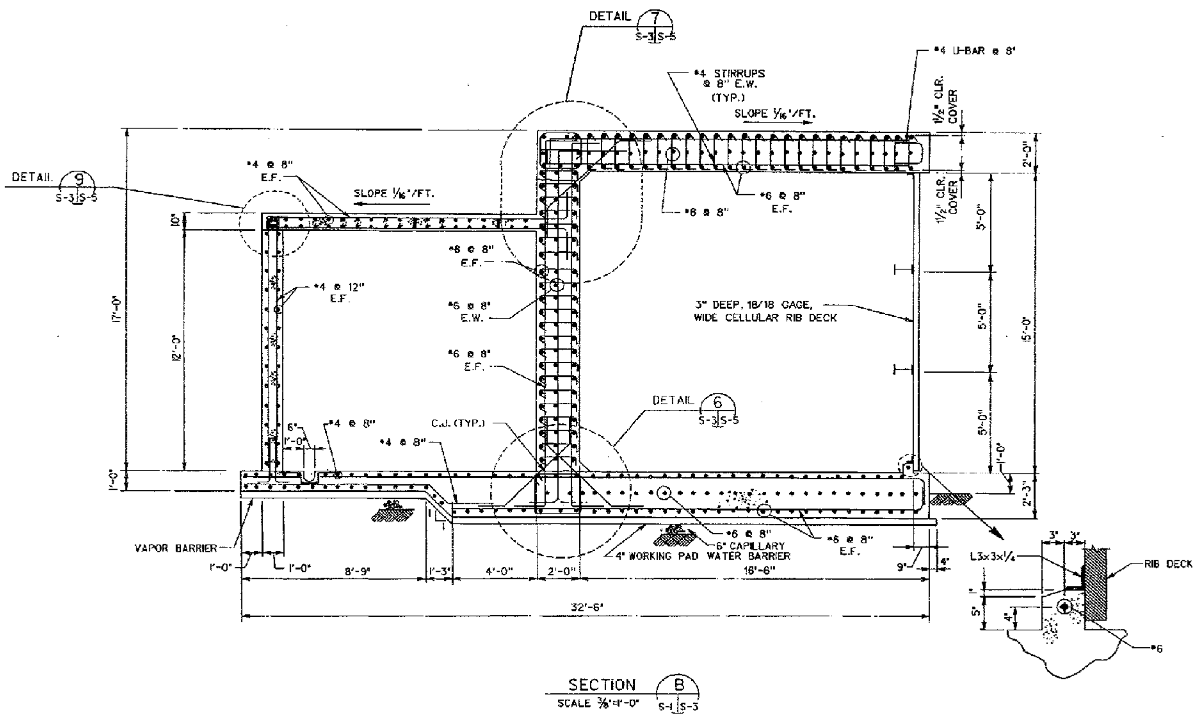
PLAN VIEW OF BUILDING 85 MODERNIZATION CONSTRUCTION

CROSS SECTION OF SUBSTANTIAL DIVIDING WALL REINFORCEMENT



CROSS SECTION OF SUBSTANTIAL DIVIDING WALL REINFORCEMENT

CROSS SECTION OF CORRIDOR WALL REINFORCEMENT



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